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DEFENSE COMMUNICATIONS ENGINEERING CENTER

TECHNICAL NOTE NO. 6-77

PERFORMANCE MEASUREMENTS OF THE
CVSD SPEECH CODING ALGORITHM

AUGUST 1977

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This report describes a series of tests that were conducted to measure the performance of the CVSD algorithm. These tests measured the performance sensitivity of CVSD modulation with respect to the algorithm parameters. The results presented in this report show that speech intelligibility and quality of CVSD coders are most sensitive to compression ratio. As a result of these tests it is recommended that certain CVSD parameters be used for coder applications under conditions of low transmission error rates.

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PERFORMANCE MEASUREMENTS OF THE CVSD

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AUGUST 1977

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FOREWORD

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I. INTRODUCTION

A set of experiments was conducted to evaluate the performance of the Continuously Variable Slope Delta (CVSD) speech coding algorithm. These experiments quantitatively measured the performance sensitivity of CVSD coding with respect to the algorithm parameters.

The parameters examined included time constants, compression ratio, and filter bandwidths. The performance of a CVSD coder in terms of speech quality and intelligibility depends on the values of these parameters. Performance also depends to some extent on the type of implementation; that is, analog or digital.

In addition to measuring the relative sensitivity of the algorithm to the basic parameters, these experiments were also used to determine an appropriate set of parameters for DCS applications.

It was found that CVSD performance is most sensitive to compression ratio. Relatively high values of compression ratio result in the best performance. In addition, the results indicate a user preference for a filter bandwidth of 3 kHz compared with a bandwidth of 4 kHz. Based on these results, certain parameters have been selected for CVSD coder operation under conditions of moderate transmission bit error rates.

II. BACKGROUND

Results from the Narrowband Consortium tests [1] show that the
performance of CVSD coders depends on such factors as the condition
of the input signal and transmission error rate. For example, it has
been found that there is a degradation in speech quality when speech
synthesized by a linear predictive coding (IPC) terminal is applied
to a CVSD coder. Experimental evidence suggests that modifications
of the CVSD parameters can result in improved performance of this
LPC tandem configuration.

In a tactical communications environment, there is a requirement
for CVSD coder operation under conditions of a 10% transmission error
rate. However, in the Defense Communications System (DCS), error
rates are expected to be less than 0.1%. These two different require-
ments impose different constraints on the CVSD parameter sets. One aim
of the tests described here is to determine if there is any significant
difference in the performance of CVSD coders whose parameters are optimized
to satisfy these different requirements.

The design of the CVSD digital voice coder is illustrated by the
block diagram shown in Figure 1; this diagram shows how the binary
transmission data and output speech are derived. The function of the
logic circuit is to generate a pulse whenever three successive
transmission bits are identical. The basic parameters of the CVSD
algorithm are:

2.
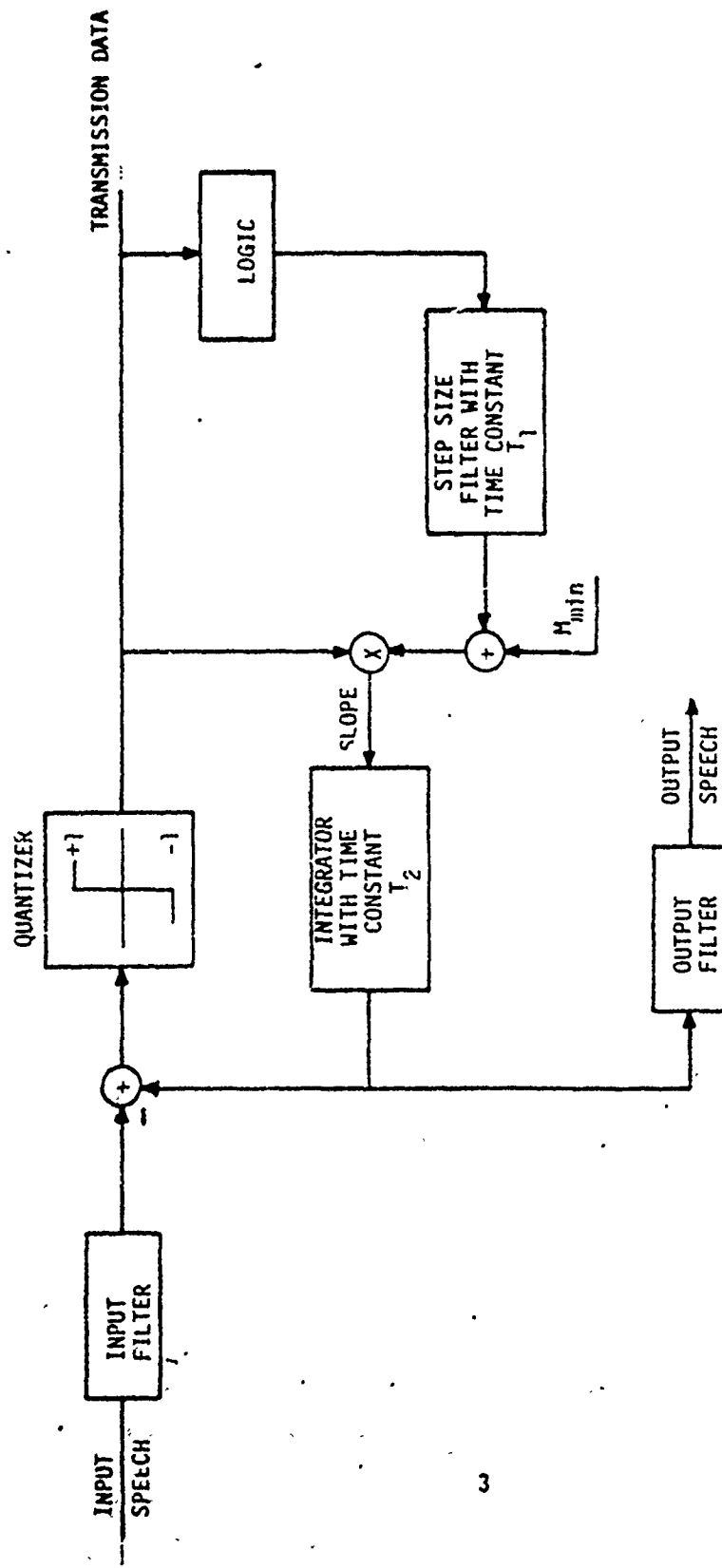
Figure 1. CVSD Algorithm

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a. Input and Output Filter Bandwidth

b. Maximum Slope, M_{max}

c. Minimum Slope, M_{min}

d. Step-Size-Filter Time Constant, T_1

e. Integrator Time Constant, T_2.

The ratio of maximum slope to minimum slope is often called compression ratio. The performance of a CVSD coder in terms of speech quality and intelligibility depends on the values of these parameters. Performance also depends to some extent on the type of implementation; that is, analog or digital circuit implementation.

III. TEST DESCRIPTION

Tests were performed to measure quantitatively the performance sensitivity of the CVSD algorithm with respect to time constants, compression ratios, and filter bandwidths. The Sylvania Programmable Signal Processor (PSP) was used to simulate the CVSD coder operating in real time. The details of the simulation are described in the Sylvania final report [2]. A variety of CVSD parameter sets were selected and tested using the PSP simulation. In addition, a CVSD coder built by Codex Corporation was tested. This coder is a digitial circuit implementation that was designed to optimize speech quality under conditions of moderate transmission error rates. The details of the Codex CVSD speech terminal are included in the Codex final report [3].

In these tests the speech coders were operated at a transmission rate of 16 kb/s with no transmission errors. This condition closely approximates operation in the DCS where error rates are expected to be less than 0.1%. The performance of the CVSD coders was measured in terms of both intelligibility and quality. The Diagnostic Rhyme Test (DRT) was used to measure word intelligibility [1]. The DRT employed three speakers using one-half of a full word list; the speakers consisted of two males and one female. In the set of tests described, the Quality Acceptance Rating Test (QUART) was used to measure quality [4]. It is generally accepted that a five point different between quality test scores represents a significant difference in speech quality. All intelligibility and quality testing was accomplished by Dynastat Corp.

IV. RESULTS

1. COMPRESSION RATIO

a. <u>Intelligibility</u>. In order to measure the effect of compression ratio on output speech intelligibility, tests were performed using the PSP with four different compression ratios ranging from 10 to 150. The remaining parameters were fixed at the following values:

$$T_1 = 6.3 \text{ ms}$$
$$T_2 = 10 \text{ ms}$$

Filter Bandwidth = 3 kHz

Figure 2 is a plot of DRT scores corresponding to the four different compression ratios. It should be recognized that DRT scores above 90 represent highly intelligible systems. This graph shows that intelligibility scores generally increase if the compression ratio is increased from 10 to 150. The DRT scores are maximum when corresponding to a compression ratio of 150; the scores are minimum for compression ratios in the range of 10 to 20. For male speakers the difference between maximum and minimum scores is 2.9 points; the standard error for this DRT is approximately 1.0. For female speakers the difference between maximum and minimum scores is 5.2 points with a standard error of approximately 1.0. These results indicate a measurable and statistically significant improvement in the intelligibility of speech processed by a CVSD coder if the compression ratio is increased from 10 to 150. Additional tests with a compression ratio of 200 did not indicate much improvement in performance compared with a compression ratio of 150; also with a compression ratio of 200 performance was degraded under conditions of transmission errors.
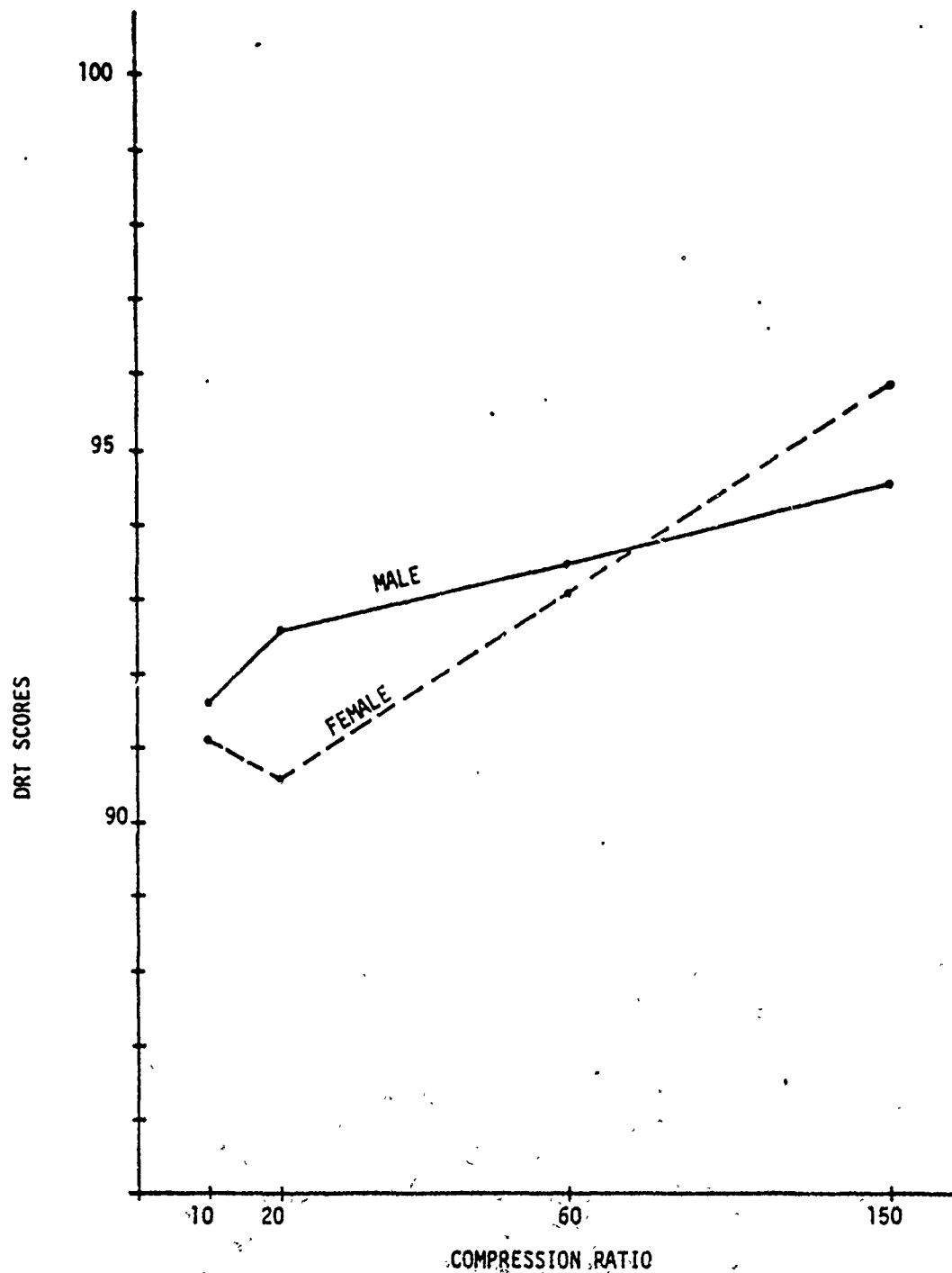
Figure 2. Intelligibility Scores

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b. <u>Quality</u>. Quality measurements were accomplished using the QUART which assigns a numerical rating to predict user preference for communications systems. Figure 3 is a plot of QUART scores corresponding to four different compression ratios. The standard error of these quality scores is approximately 2.5. The difference between the maximum and minimum QUART scores is 10.1 points. These results indicate that quality scores increase monotonically with compression ratio and that there is a significant user preference for the highest value of compression ratio. Figure 4 shows the relation between quality scores and the percentage of people who find the communications acceptable for routine use.

2. FILTER BANDWIDTH

a. <u>Intelligibility.</u> The effects of changing the input and output filter bandwidths were measured. Table I lists the DRT scores corresponding to filter bandwidths of approximately 3 kHz and 4 kHz; these are the cutoff frequencies of the low pass output and input filters which are seventh order elliptic filters. The standard error of each DRT is shown to the right of the score. Although the intelligibility score for the female speaker is unchanged, the score for the male speakers is slightly higher, corresponding to the increased bandwidth. With a compression ratio of 150, the DRT scores are increased slightly for male speakers and decreased for female speakers, corresponding to the increased bandwidth. These results indicate that there is no significant overall difference in DRT scores corresponding to the two filter bandwidths.
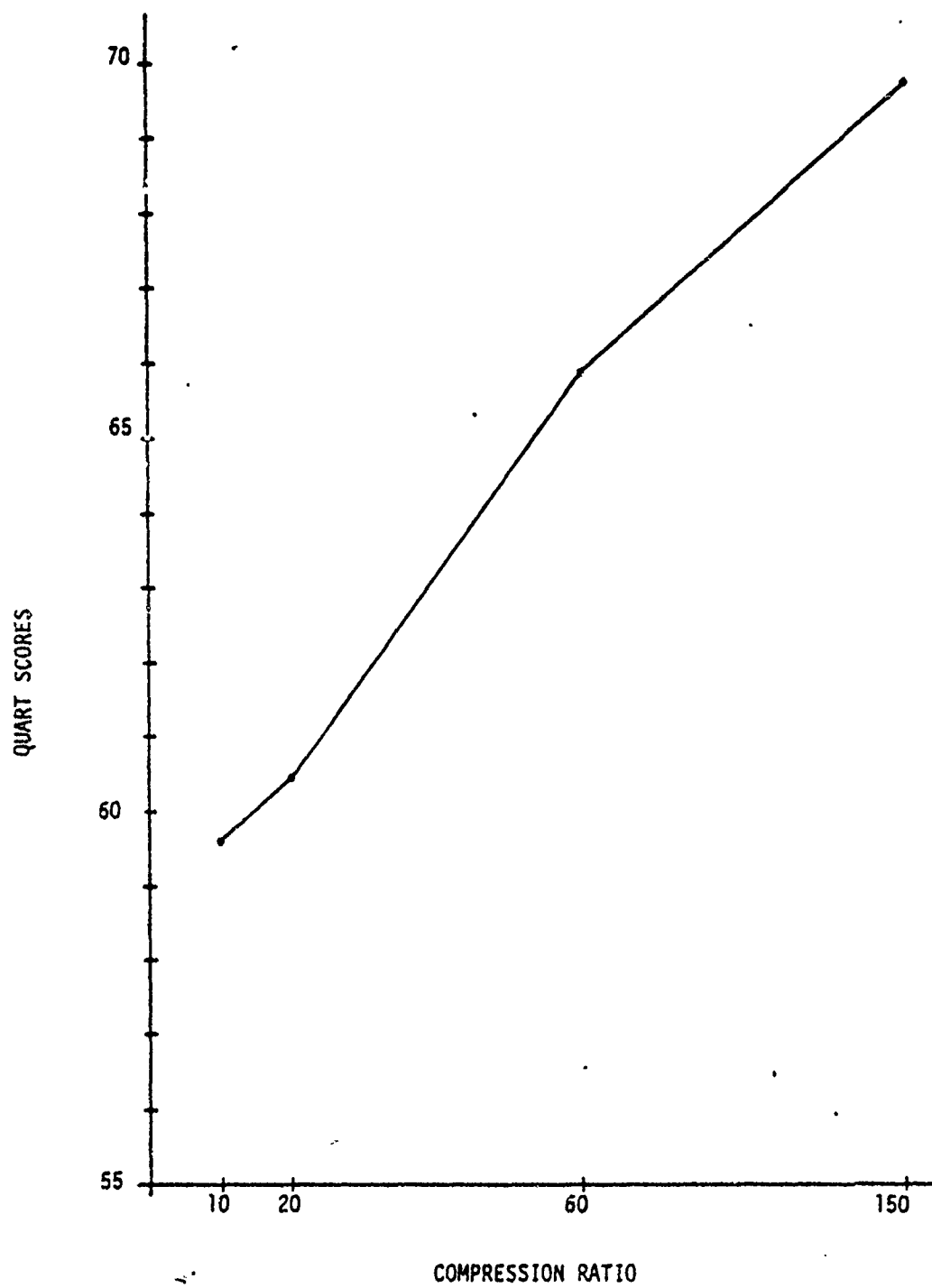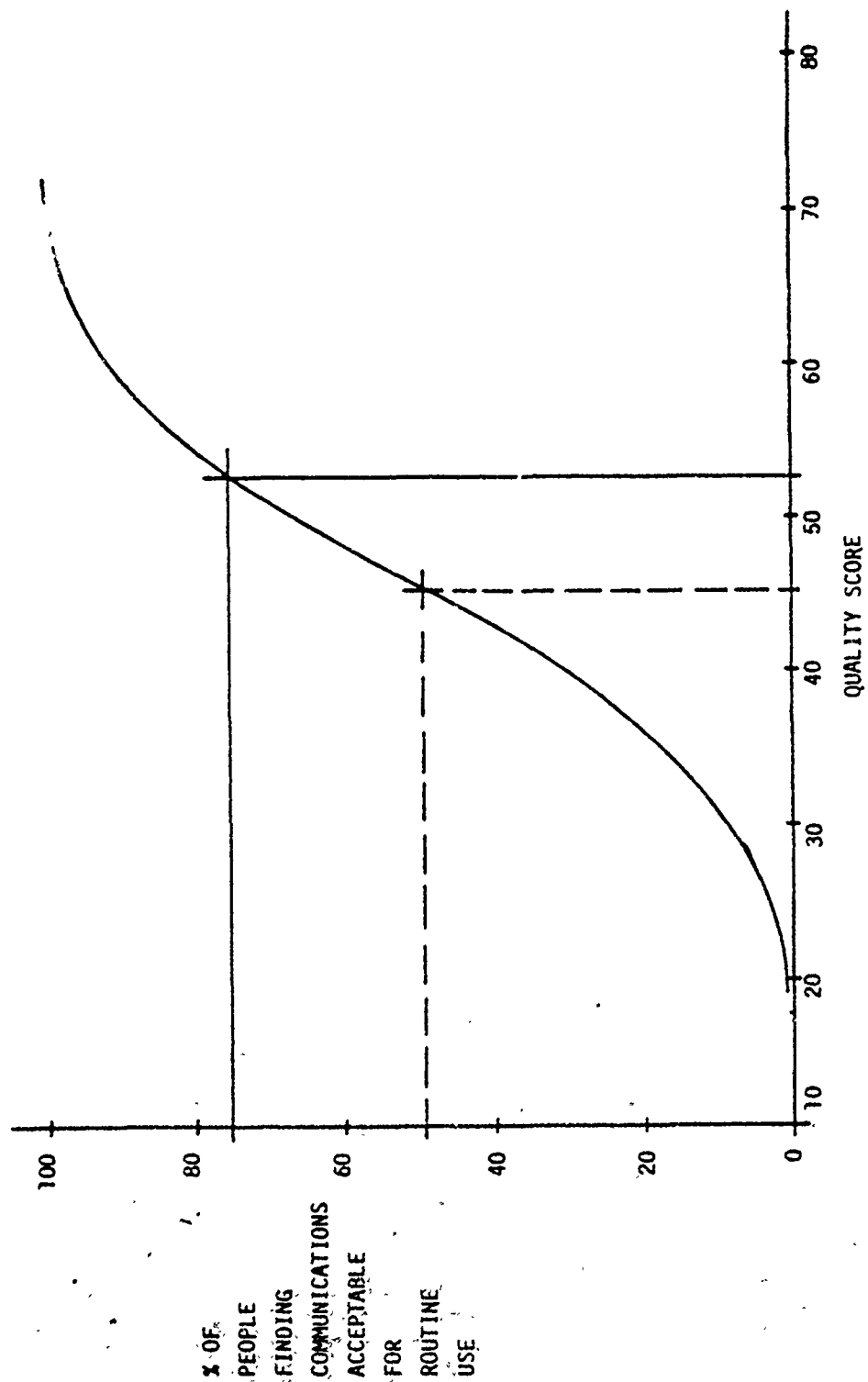
Figure 3. Quality Scores

Figure 4. Relationship of Quality Scores to Acceptability

% OF
PEOPLE
FINDING
COMMUNICATIONS
ACCEPTABLE
FOR
ROUTINE
USE

QUALITY SCORE

TABLE I. FILTER BANDWIDTH TEST

COMPRESSION RATIO.	FILTER BANDWIDTH	DRT SCORE		QUART SCORE
		MALE	FEMALE	
10	3 kHz	91.6 ± .75	91.1 ± .88	59.6 ± 2.3
	4 kHz	93.1 ± .81	91.1 ± .94	55.2 ± 1.6
150	3 kHz	94.5 ± .85	95.8 ± .48	69.7 ± 3.2
	4 kHz	95.1 ± .89	92.2 ± .80	63.6 ± 3.2

TABLE II. TIME CONSTANT TEST

T_1	T_2	DRT SCORE		QUART SCORE
		MALE	FEMALE	
6.3 ms	1 ms	91.6 ± .75	91.1 ± .88	59.6 ± 2.3
	20 ms	91.7 ± .58	90.2 ± 1.0	57.9 ± 1.6
20 ms	1 ms	91.0 ± .34	87.1 ± 1.4	56.7 ± 1.3
	20 ms	90.5 ± .96	88.0 ± 1.3	53.6 ± 1.0

b. <u>Quality.</u> The results of the quality tests are also listed in Table I. These results indicate a rather significant user preference for the 3 kHz bandwidth compared with the 4 kHz bandwidth. The improvement in the QUART score is approximately 5 points when the cutoff frequency is reduced from 4 kHz to 3 kHz.

3. TIME CONSTANTS

Tests were performed to measure the performance sensitivity of the CVSD algorithm with respect to the time constants of the integrator and step-size-filter. For these tests the following parameters were set:

$$\text{Compression ratio} \approx 10$$
$$\text{Filter Bandwidth} \approx 3 \text{ kHz.}$$

a. <u>Step-Size-Filter.</u> Table II contains DRT scores corresponding to two different values of T_1. These results show that intelligibility is generally less for the time constant of 20 ms. Also shown in Table II are the quality scores corresponding to the two different values of T_1. The quality scores indicate a general reduction in user preference for the higher value of T_1.

b. <u>Integrator.</u> Table II also lists the DRT and QUART scores corresponding to two different values of the integrator time constant, T_2. These results suggest that if the integrator time constant is varied within the limits of 1 ms to 20 ms there is negligible change in intelligibility and user preference.

4. COMPARISON OF CVSD CODERS

The CVSD coder proposed for use in the TRI-TAC secure voice system is based on the following set of parameters:

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$$\text{Filter Bandwidth} \approx 4 \text{ kHz}$$

$$\text{Compression Ratio} \approx 12$$

$$T_1 = 6.3 \text{ ms}$$

$$T_2 = 1.0 \text{ ms.}$$

This particular algorithm (CVSD-A) was simulated on the PSP. The corresponding DRT and QUART scores are listed in Table III. The CVSD coder built by Codex Corporation is based on the following set of parameters (CVSD-B):

$$\text{Filter Bandwidth} \approx 3 \text{ kHz}$$

$$\text{Compression Ratio} \approx 166$$

$$T_1 = 2 \text{ ms}$$

$$T_2 = 8 \text{ ms.}$$

DRT and QUART scores corresponding to the Codex terminal are listed in Table III. Also included in Table III are the scores corresponding to a PSP simulation of a version of CVSD-B. The results indicate a strong user preference for CVSD-B over CVSD-A.

TABLE III.   COMPARISON OF CVSD CODERS

| | DRT SCORE | | QUART |
	MALE	FEMALE	SCORE
CVSD-A (PSP)	93.1 ± .81	91.1 ± .94	55.2 ± 1.6
CVSD-B (PSP)	95.2 ± .55	93.1 ± .68	67.6 ± 3.2
CVSD - CODEX	94.1 ± .38	91.9 ± .70	71.5 ± 3.7

V. CONCLUSIONS

Speech intelligibility and quality of CVSD coders are sensitive
to the values of certain algorithm parameters. In particular, it
was found that CVSD performance is most sensitive to compression ratio;
the highest value of compression ratio resulted in the best performance.
In addition, the quality scores indicated a significant user preference
for a filter bandiwdth of 3 kHz.

Results have also shown that within the ranges tested, the time
constants of the integrator and step-size-filter have small effects on
quality and intelligibility. However, these time constants do affect
performance under conditions of high transmissions error rates.
Therefore the following time constants, which have been selected for
such conditions, are appropriate:

$$T_1 = 6.3 \text{ ms}$$
$$T_2 = 1.0 \text{ ms}$$

Although the tests performed were by no means exhaustive, the
results can be used to quantify the performance of CVSD coders
corresponding to different parameter sets. The test results show that
the CVSD-B parameters provide the best performance compared with the
other parameter sets including the CVSD-A parameters. The quality tests
indicated the greatest preference for the Codex CVSD coder. The test
results also indicate that the following CVSD parameters should
provide performance comparable with CVSD-B.

Filter Bandwidth   =   3 kHz

Compression ratio =   150

T_1 =   6.3 ms

T_2 =   1.0 ms

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